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"Development of Novel Instrumentation to Characterize Aerosol Insets and Cloud Particles"

Topic No. N01-047
Phase I – Phase II Interim Funding
Final Report

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1. Description of progress

During the first 30 days SPEC delivered to the Naval Post Graduate School an aerosol inlet calibration device with instructions for use on the Navy Twin Otter research aircraft.

Since then, SPEC has continued work on the design of the 2D-S (stereo) cloud particle probe. The custom 128-photodiode array has been fabricated and tested by Thermo Centrovision (TCV) and is, from the tests so far conducted, behaving beyond the requirements specified prior to manufacture. Work is ongoing for the both the digital and analog electronics. The digital electronics have been simulated and a prototype design is being pursued for the analog electronics. Footprint constraints for the analog electronics have been estimated and design of the laser and optical system are currently under way.

1.1 Electronics Progress

1.1.1 Diode Array Manufacture

The photodiode arrays have been manufactured and are undergoing testing, with one problem coming to light during this process. The specifications supplied by SPEC to the manufacturer of the arrays call out a 42.5 by 50 micron active area that is photosensitive, but the manufacturing process yielded an unforeseen active area that can be explained looking at **Figure 1**.

The vertical row of squares are the desired active photosensitive regions. The cross-hatched regions that merge with each of these active areas represent conducting tracks that run the photo induced currents from the active area to a bond pad elsewhere on the die. Surrounding the cross-hatched areas is a region of unwanted photosensitive area.

Tests under room light were done by masking and unmasking only the active area in the center (the vertical row of rectangles), with the requirement that when covered, the photocurrent produced would be 10% or less of that produced uncovered. This was not the case and rendered the array unacceptable in its present condition. SPEC worked with TCV to define a mask, the requirements of which follow:

> *The deposited photo mask should be larger than the active area of the array by 10 microns in both length and width. So the dimensions for the slit in the photo mask should be 60 microns x 7.355 mm. This gives 5 microns clearance per side for elements 50 um wide and 5 microns on each end of the 7.345 mm array.*

Subsequent tests at TCV show that masking the area around the desired active elements limits the unwanted photocurrent contribution to acceptable levels. TCV is having a production mask designed and manufactured to correct the problem.

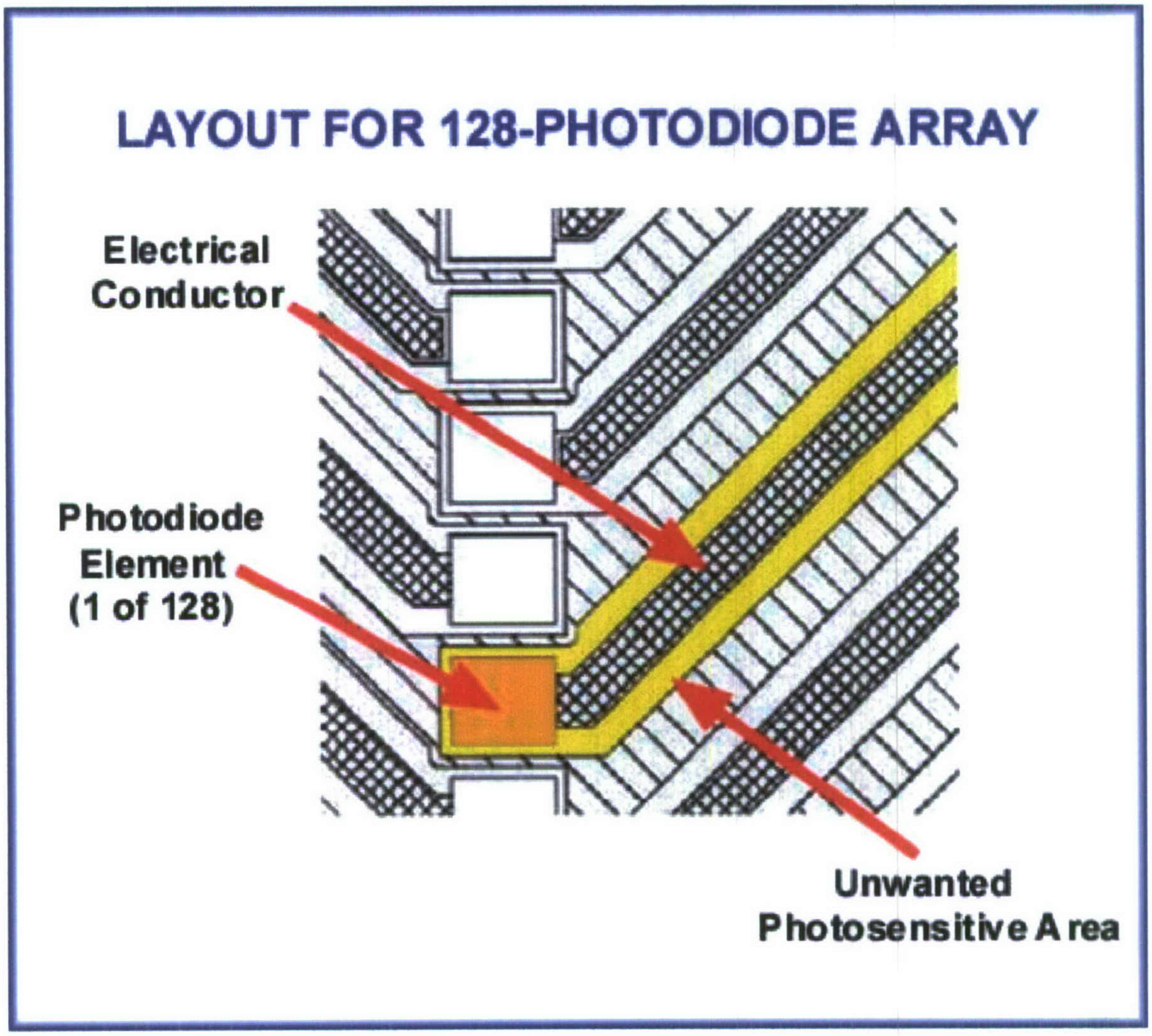

Figure 1. Layout of 128-Photodiode array supplied by its manufacturer, Thermo Central Vision, showing unwanted photosensitive area.

1.1.2 Photodiode Amplifier Circuit

SPEC is currently prototyping an amplifier circuit based on the original simulated designs and readily available parts. Several possible circuit solutions will be tested using this prototype, which will also amplify the center and end diode elements for analyzing laser intensity profile. A preliminary parts placement taking into account expected integrated circuit packages was done to gain confidence in fitting the required 128 individual circuits into the allotted circuit board space, showing that it should be possible.

Figure 2 shows the dimensions (in inches) and part numbers for a flex circuit that provides 160 impedance controlled signals in a cabled connector that has been identified for routing the 128 amplified and compared diode array output signals from the analog boards to the digital board. This cable solution from SAMTEC ensures high signal integrity, low noise, and the required signal density for the application, due to the presence of a ground plane beneath the signal layer, removing the necessity for ground wires for each signal, and a high density 160 pin connector.

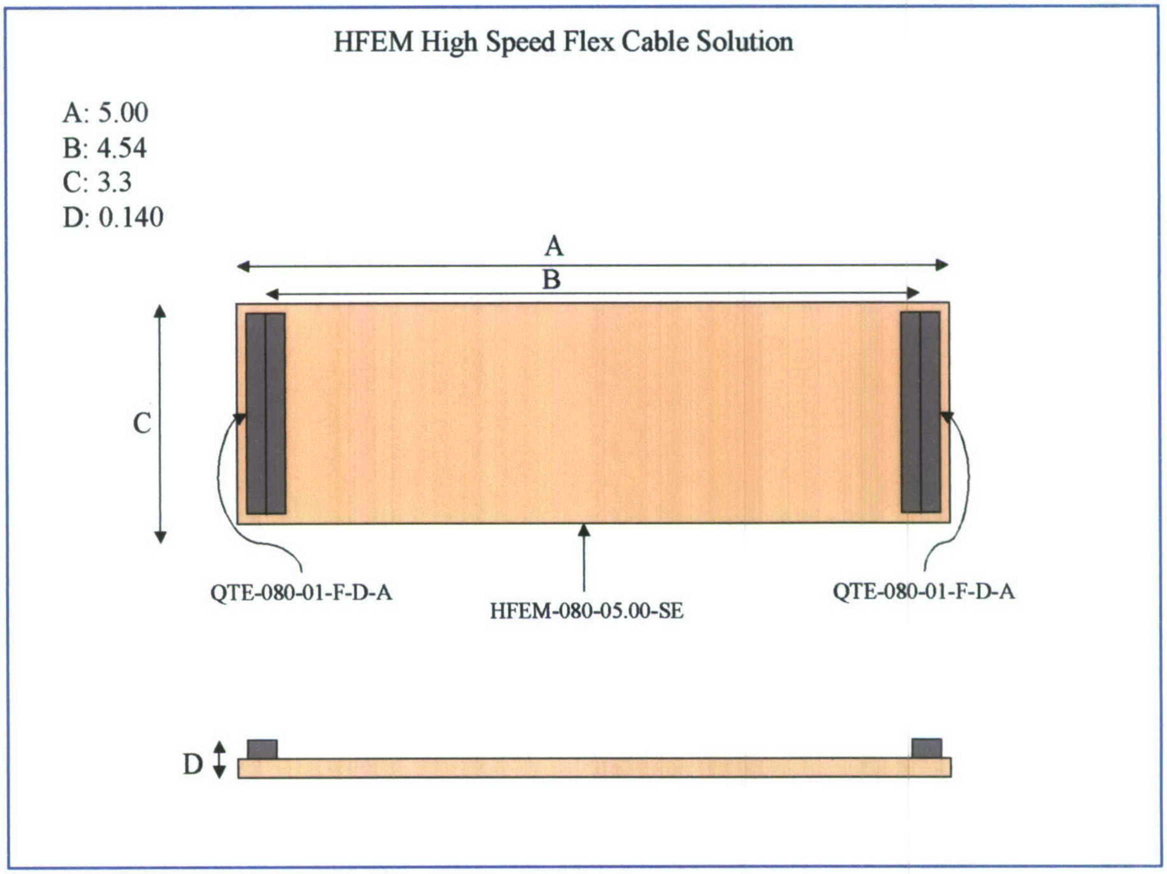

Figure 2. High speed, impedance controlled cable solution from SAMTEC.

1.1.3. Digital Electronics

Design and simulation of the image compression are ongoing, as is the design of a High Level Data Link and Control (HDLC) communications protocol circuit. The HDLC circuit will provide a standard communications link to transfer the large data quantities from the probe to off the shelf communications cards that will go into the future data system.

1.2 Optical Design

During this period, optical design work concentrated on the selection of a laser and delivery optics for the 2DS. **Figure 3** is a schematic of the photodiode array showing the overall length and width of the array. Not all 128 elements are shown in this photo. The array length is 7.35 mm long and the width is the width of one individual pixel, 50 microns. The magnification of the imaging system (i.e. the pixel size resolution of the probe) will determine the necessary laser beam size in the sample volume.

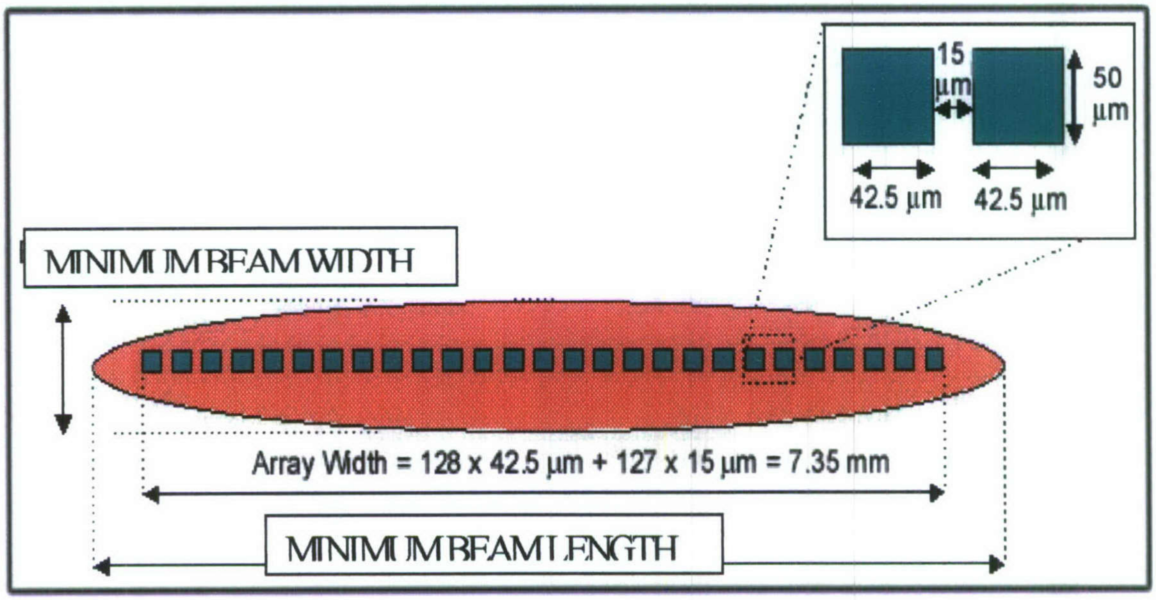

Figure 3. Schematic drawing of photodiode array with overlapping laser beam.

The actual pixel size of 42.5 microns and the dead space between pixels of 15 microns adds to an effective pixel size of 57.5 microns. To arrive at 10 micron/pixel resolution in the sample volume would require an imaging system magnification of M=57.5/10 = 5.75. The width of the sample volume will be the array length divided by the magnification, or sample volume width=7.35 mm/5.75 =1.28 mm. Based on this dimension, the laser beam in the sample volume must be at least 1.28 mm wide. The thickness of the beam should be as thin as practically possible to give the highest radiant intensity on the array.

The laser diode selected for this application is a Hitachi HL6501MG diode that operates at 660 nm and has a peak output power of 35 mW. The diode emitting area is 1 micron x 3 microns and the divergence angles are 8.5° and 22°. The shape of the output beam from a laser diode is an expanding ellipse. The basic approach to the design of the laser beam shaping optics is to use one lens to collimate the beam to the minimum array width size and use a pair of cylindrical lenses to compress the minor axis of the elliptical beam to increase the energy density. It is also desirable to have the laser beam energy as uniform as possible from pixel to pixel on the array. Although the gain can be adjusted on each individual pixel, starting with a uniform intensity will simplify this process. The third factor to consider in the design is to oversize the beam to accommodate any misalignments that can occur during flight

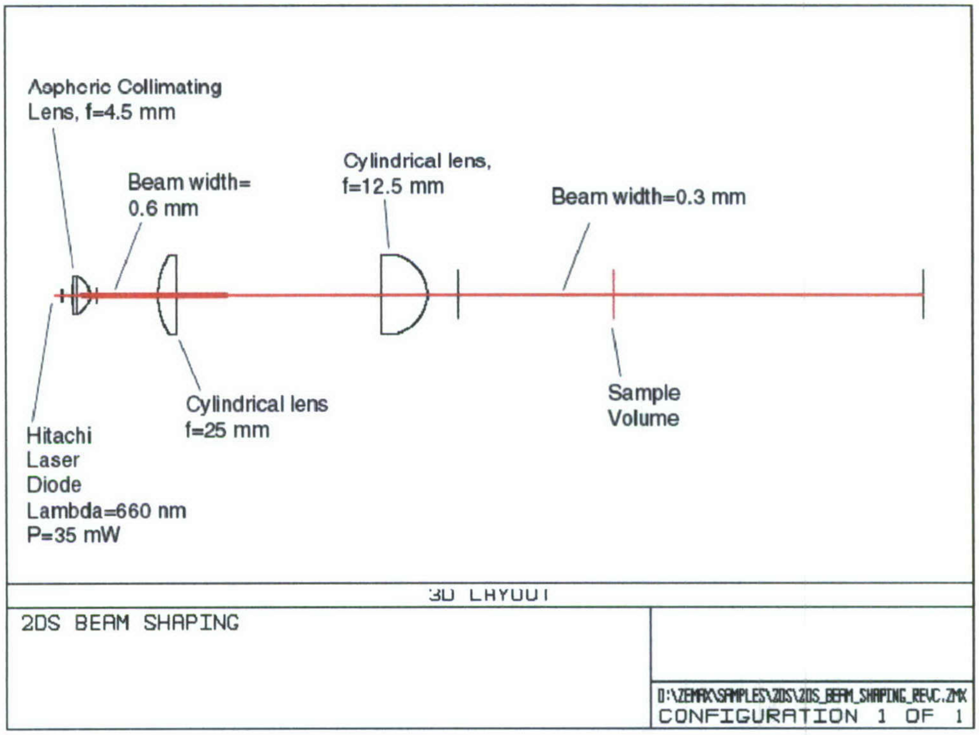

Figure 4. Zemax™ ray trace showing laser beam collimation and compression in minor axis.

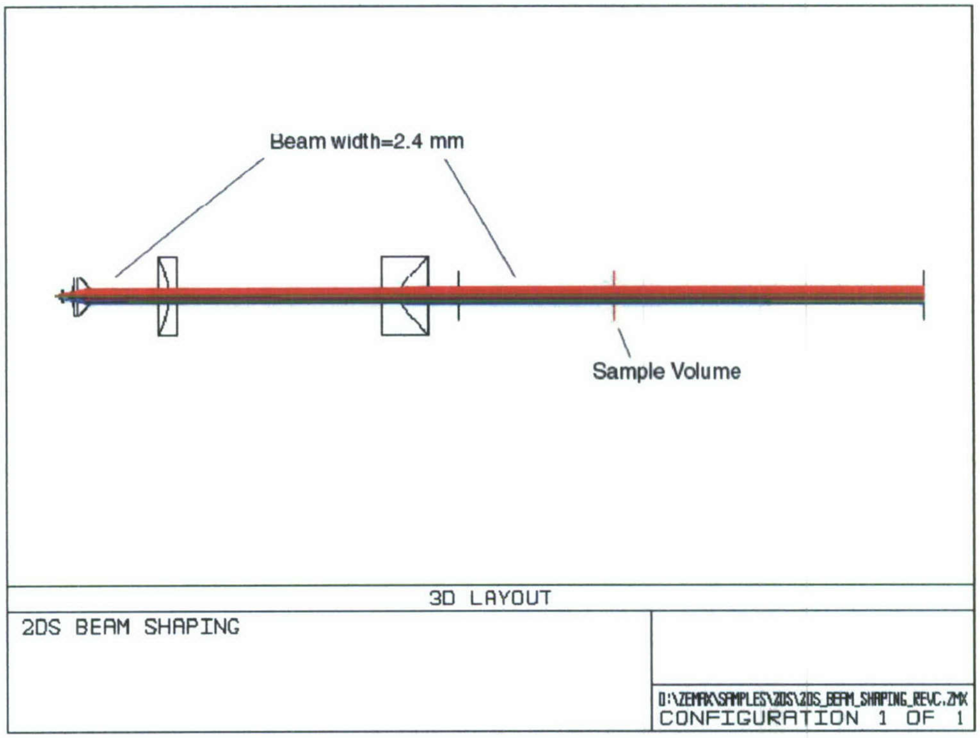

Figure 5. Zemax™ ray trace showing laser beam collimation and no compression in major axis.

Figure 4 is a ray trace created in Zemax™ optical design software showing an initial design for the 2DS beam shaping. The laser is collimated with an aspheric lens and then the minor axis is compressed with a pair of cylindrical lenses. The cylindrical lenses are separated by the sum of their focal lengths and have a magnification of the ratio of their focal lengths. The magnification in this case is 12.5/25=0.5.

Figure 5 is the same ray trace as **Figure 4** rotated 90° about the optical axis. **Figure 5** shows the major axis of the elliptical beam is collimated to 2.4 mm. The minor axis of the ellipse is collimated to approximately 0.6 mm. The cylindrical lenses decrease the beam size to 0.6 mm x 0.5 = 0.3 mm. The beam in the sample volume is then 2.4 mm wide x 0.3 mm thick. In the actual 2DS probe, two of these beams will intersect perpendicular to one another in the sample volume.

Figure 6 is a plot of the radiant intensity of the laser beam passing through the sample volume. This plot is only a first order estimate of the intensity distribution in the beam. It assumes a single gaussian distribution for the laser diode in both divergence planes. A real laser diode has a different gaussian or super-gaussian energy distribution in each of the divergence planes. To first order, however, this will give a reasonable estimate of the energy distribution. It is also probably much more realistic than assuming a uniform energy distribution from the source.

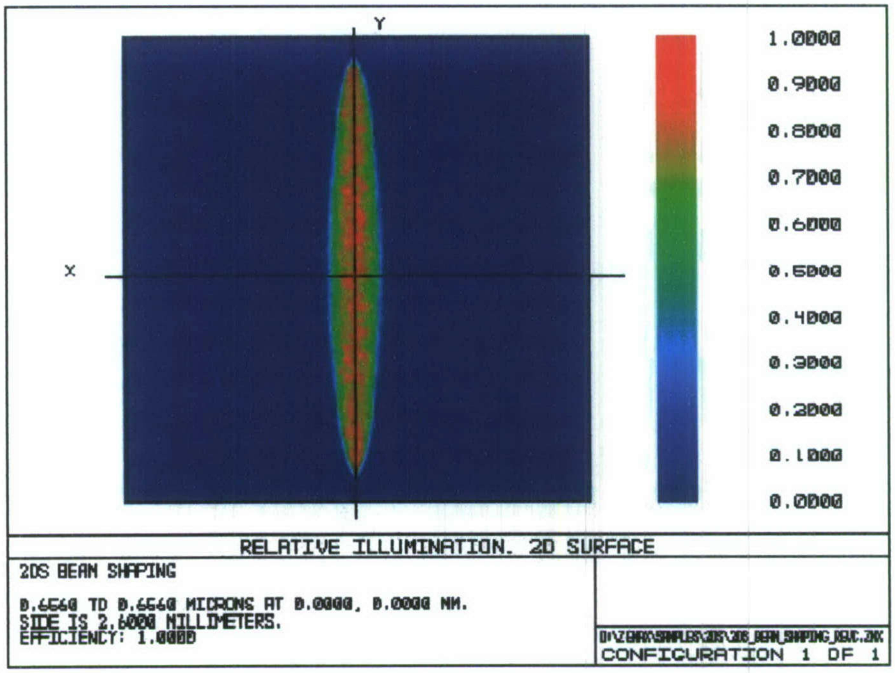

Figure 6. Relative radiant intensity of laser beam cross-section passing through the sample volume.

Figures 7 and **8** show x and y energy distribution cross-sections, respectively. **Figure 7** shows a beam width of approximately 0.2 mm and the laser energy peaking in the center of the beam. The 0.2 mm thickness is a slight underestimate of the 0.3 mm dimension predicted by the ray trace. The actual beam width will be larger than that predicted by the model. The model is based on the divergence angles of the diode measured at the full-width half-maximum (FWHM) point, and does not include the "tail" of the energy distribution present in the real diode. The design will result in a conservative estimate of beam size and energy distribution. The drawback of this approach is that the actual radiant intensity may be slightly lower than predicted by the model.

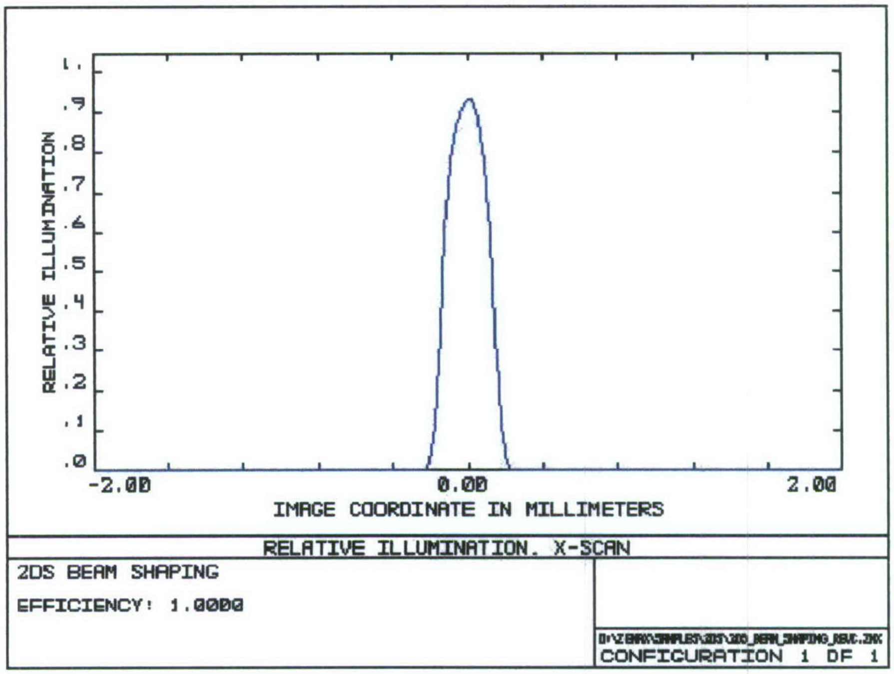

Figure 7. X-cross section of laser beam intensity shown in **Figure 6**.

Figure 8. shows the relative radiant intensity along the width of the laser beam in the sample volume. The plot shows the beam width approximately 2.4 mm. The actual sample volume will only be 1.28 mm as mentioned above. This is the only portion of the beam that will be imaged directly onto the array. The relative illumination over the center 1.28 mm of the beam is fairly flat. This should result in a minimal gain adjustment on the pixels of the array.

During the next period, this design will be prototyped in the laboratory and evaluated. Work will also continue on the imaging optics design to image the particles in the sample volume onto the photodiode array.

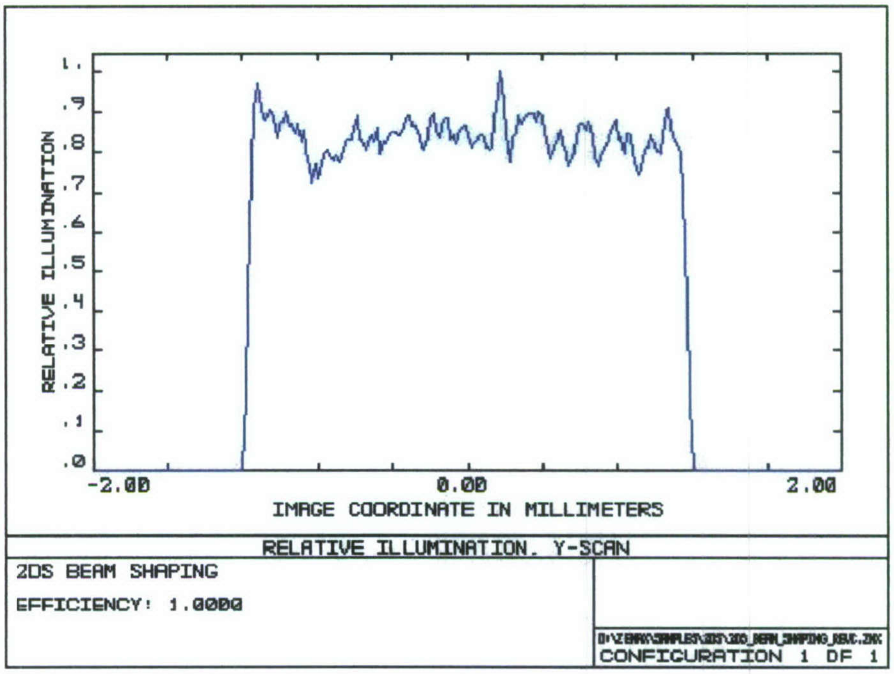

Figure 8. Y-cross section of laser beam intensity shown in **Figure 6**.

2. Work to be completed during the next period

During the beginning of Phase II, prototypes of both the analog photodiode amplifier and the laser and optical system will be built and tested. Schematic capture of the diode array board will begin based on the test results. Mechanical design and packaging of the instrument will commence after verification of the optical system.

The digital electronics schematic capture will also begin, with the goal of a prototype board layout to be completed for testing. Simulated digital designs will be moved to programmable hardware (complex programmable logic devices, or CPLD's) capable of running at the speeds necessary for the high frequency system. Efforts will be made to create a standalone digital system (no diode amplifier board necessary) for integrating into the data system.

A data system for use as a laboratory test platform will be defined and software contractors identified and employed to implement it.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

During the 90-day interim funding period, SPEC (1) delivered to the Naval Post Graduate School an aerosol inlet calibration device with instructions for use on the Navy Twin Otter research aircraft and, (2) performed preliminary design of the optics and electronics for the 2D-S (stereo) cloud particle probe. The custom 128-photodiode array for the 2D-S probe was fabricated and tested by Thermo Centrovision (TCV), and is, from the tests so far conducted, behaving beyond the requirements specified prior to manufacture. The digital electronics have been simulated and a prototype design is being pursued for the analog electronics. Footprint constraints for the analog electronics have been estimated and design of the laser and optical system are currently underway. Preliminary design of the optical imaging system was also performed during this period, concentrating on the selection of a laser and delivery of prototype optics for the imaging system. The laser diode selected for this application is a Hitachi HL6501MG diode that operates at 660 nm. The basic approach to the design of the laser beam shaping optics is to use one lens to collimate the beam to the minimum array width size and use a pair of cylindrical lenses to compress the minor axis of the elliptical beam to increase the energy density. The laser and prototype optics were set up in the laboratory in preparation for tests to be conducted in Phase II.

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